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ECONOMIC ASPECTS OF WASTEWATER REUSE: THE EGYPTIAN CASE

Raouf F. Khouzam

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7 Boulos Hanna St. Dokki, Cairo, Egypt
Tel: (202) 3370810 – (202) 7485553 – (202) 7602882
Fax: (202) 7616042. Email: erf@idsc.net.eg. Website: http://www.erf.org.eg

Abstract

Several regions in the world suffer water stress. As only a small part of withdrawn water is consumed, properly recovering, treating and suitably reusing wastewater will help to reduce the supply-demand gap and save the environment from the adverse effect of dumping polluted wastewater. A simulation model is built to identify the main variables, key relationships and examine their dynamics. The model is applied to Egypt. The main findings point to the fact that the pressure population growth exerts on natural resources can be alleviated by adopting suitable policy intervention tools. Furthermore, the most effective policy tools are those based on economic criteria.

Introduction

Water shortage is a global issue. Several regions in the world have been suffering from water stress and shortage. Approximately, 436 million people living in 29 countries suffer water scarcity (Gardner-Outlaw and Engelman 1997). By the year 2025, 2.6-3.1 billion people could be suffering water deficiency (PAI 2002). In the Middle East and North Africa (MENA), one of the driest regions in the world, the issue is inextricable. Of the global renewable water resources (40 thousand bcm/year), MENA gets less than 1 percent to accommodate more than 5 percent of the world population (World Bank 1995).

Only a small part of withdrawn water is consumed; the rest returns to the system. Based on estimates of the Egyptian Ministry of Industry and Mineral Wealth, industrial consumptive use is about 15 percent. Municipal consumptive use is difficult to estimate because only 77 percent of urban and 5 percent of rural population are connected to sewerage systems (EPIQ 1998). Roughly, it is in the vicinity of 5 percent. In agriculture, about two thirds of irrigation water returns to the irrigation-drainage system.

Recovering, properly treating and suitably reusing wastewater will help reducing the supply-demand gap and save the environment from the adverse effects of dumping polluted wastewater. Wastewater reuse is adopted at a limited scale worldwide. The economics of such scheme have hardly been studied. Economic aspects of this practice include costs of collecting, treating and distributing wastewater, benefits associated with making more water available for final consumption and intermediate use, and benefits resulting from saving the negative externalities associated with dumping polluted water in the environment. The scope of this work is limited to the costs of recovering and treating wastewater and the benefits of making more water available as an intermediate product in the agriculture sector in Egypt. Other aspects are left for future research.

A simulation model has been built as a tool of analysis. It identifies main variables, key relationships among them and examines the different dynamics of present and future people-food-water system. The model is applied to Egypt as a representative of the Central region in the Arab nation.[1] Egypt is selected because it has been practicing wastewater reuse for decades and intends to expand this practice; consequently data and information are available.

Rigidity of water supply, growing demand in association with the lack of institutions capable of managing water deficit and degradation altogether worsen the impact of the supply-demand gap on development. Rigidity of water supply is due to the high cost of increasing the quantity of water available such as in the transportation of water by pipelines as in the case of the Libyan Great Man-Made River, or by bags in the sea as in the Medusa Bag project to transport water from Turkey to Cyprus, through desalination, water reuse, dams, improved management…etc. Growth in water demand is the result of burgeoning population and growing economic sectors. Water deficit is exacerbated by unequal access to water resources and practices that degrade rather than conserve water quality.

The paper is presented in six sections. Since more than 80 percent of Egypt's water demand is for food production, the paper starts by considering the food situation in section one. Available water resources are reviewed in section two. The theoretical framework is presented in section three. The model structure is introduced in section four. Simulation results are presented in section five. Conclusions are given in Section six.

Of the main findings of this research the adverse effect of the pressure that population growth exerts on natural resources can be alleviated by adopting suitable policy intervention tools. Furthermore, the most effective policy tools are those based on economic criteria.

1. Food Situation

Being aware of the growing food needs, Egypt exerted significant efforts to raise land productivity, reclaim desert soil, and expand irrigated land. Between 1961 and the year 2000, the cereals yield increased from 1.18 to 3 metric ton (mt)/acre, wheat from 1 to 2.5 mt/acre, rice from 2 to 3.7 mt/acre, maize from less than 1 to 3.55 mt/acre, and sugarcane from 36 to 49 mt/acre (FAO: Primary Crop Production, 2001). In addition to vertical expansion, Egypt persistently has been reclaiming desert land. During the first half of the twentieth century, Egypt reclaimed 0.1 million acres, and 2.5 million acres in the second half. Still, more than 4 million acres are to be reclaimed during the first two decades of the twenty first century (GARPAD 1996-1997). The third path to face food needs is expanding the irrigated area so as to allow more intensive cultivation. The irrigated area increased from 6.3 million acres in 1961 to 8.2 million acres in 1997 (FAO: Irrigated Area, 2001).

In spite of Egypt's efforts to increase local food production, Egypt is a net importer of agriculture products in general. In 1961, the value of net imports of agriculture products was $180 million.[2] It rose to about $3 billion by 1997. Similarly, net imports of food and animal products increased from $74 million to more than $2 billion (equivalent to 0.73 and 12 million tons; respectively) by 1997 (FAO: Commodity Balance Sheets, 2001).

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[1] The Central region comprises Egypt, the Sudan, Djibouti, Eritrea, and Somalia.

[2] Net imports are imports mince exports.

Hefty import bills allowed Egypt not only to meet food demand of a population that grew from 28 million in 1960 to more than 62 million in 1995 (UN 1998), but also to support rising per capita food consumption. For example, the per capita cereals consumption, which provides the Egyptians with two thirds of their calories and protein intake, rose from 162 kg/year in 1961 to 250 kg/year in 1999 (FAO: Commodity Balance Sheets, 2001).

2. Water Resources

Egypt's rigid water supply, growing population, and ambitious development plans promise a deteriorating per capita water share. Table 1 displays the estimates of per capita water during the period 1955-2050. In 1955, the per capita water was 2385 m^3. In that year, total renewable water supply was estimated at 59 bcm and the population was 25 million. By 1975, Egypt managed to increase water supply to 69 bcm and the population reached 39 million; per capita water fell to 1764 m^3. By 2050, per capita water is projected to fall to 466-754 m^3 depending on population growth.

Several options are available to ameliorate the deteriorating water situation: slowing down population growth, improving the efficiency of water use, implementing upper Nile conservation projects, and relying more on non-conventional water resources such as rainwater harvest, reuse and recycling. As indicated above, the reuse of wastewater is the subject of this work.

In the late seventies, GOE, UNDP and the World Bank launched the Water Master Plan project. It produced a three-scenario plan. In the first scenario, available water supply was a constraint; the plan designed the utilization of a fixed endowment. In scenarios 2 and 3, water demand was estimated for an agriculture sector growing at 4.9 percent and 3 percent with new lands growing at 1.9 percent and 0.5 percent; respectively.

The Nile is the main source of water in Egypt. In desert areas, Egypt exploits aquifer water. Rainfall is concentrated in the north. Desalination is used at seashores for municipal uses. The reuse of wastewater has been practiced at a limited scale. Future land reclamation programs rely heavily on expanding the reuse of wastewater. Those topics are presented below in Sections 3.1-3.6; in order.

2.1 Nile

Although the longest river in the world (6825 km), the Nile discharge is relatively small because it traverses dry areas over 35 degrees of latitude from equatorial East Africa to the Mediterranean (3.5° S to 31° N). Its revenue is 1.5 percent that of the Amazon, and 6.7 percent that of the Congo River (Said 1993). The quantity of water per land unit of the basin it serves is the least: 28 thousand m^3/km^2 compared to 782 in the Amazon, 931 in the Mekong (calculated from Said 1993).

During its long trip, the Nile gets its water from two main sources: the Equatorial Lakes Plateau and the Ethiopian Highlands. The first source collects its water from year-round rain over Zaire, Tanzania, Rwanda, Burundi, Uganda, and Kenya. The average annual inflow of this source is about 33 bcm at Mongalla at the entrance of the vast Sud wetland in the Sudan where half the water is lost. Water from the Ethiopian Highlands feeds three main rivers: Sobat (14 bcm), the Blue Nile (50bcm), and Atbara (11 bcm). Accounting for losses, the average amount of water that reaches the southern borders of Egypt is about 84 bcm (Said 1993).

Regularity of river revenue depends on inter-seasonal and inter-annual variations. Seasonality is a characteristic of the water coming from the Ethiopian Highlands where its flow during the high rain season (summer) is about 40 times that of the low season (Said 1993). This source provides more than 80 percent of the Nile revenue.

Annual fluctuation is another feature of the Nile. Flood revenue records show fluctuation ranging from as low as 42 bcm in 1913/14 to a maximum of 151 bcm in 1978/9 (Abu El-Atta et al. 1985).

The risk associated with seasonal and annual variations becomes modest when compared to the more serious question of the declining trend of the river's revenue. It dropped from an average of 110 bcm in 1870-1899 (Said 1993) to 84 bcm during the period 1900-59, to 72 bcm during 1977-87, and to less than 52 bcm during 1984-87. Few interpretations are given to explain this falling trend. The first explanation suggests that the decline is a temporary part of the natural 'Hurst Phenomenon' whereby cycles of low and high flows have been taking place during the Nile history. The rather pessimistic explanation anticipates the falling trend to continue as a result of the migration of the precipitation zone southward. Migration is attributed to changes in the Earth's orbit, the greenhouse effect, and the depletion of land cover.

Nile revenues can be increased by implementing a number of conservation projects in the upper Nile region. However, this is very expensive approach. The average cost of water obtained from upper Nile projects is in the magnitude of LE 300 million/1 bcm. Furthermore, its implementation takes a long time. Hence, it cannot provide quick solutions to urgent problems. Besides, the public debt burden, and the lack of security and political stability make it difficult to gain access to international agencies to finance such expensive projects. Finally, those projects are facing tough objections by environmentalists because of their adverse effect on that natural habitat when wetlands are dried, alteration of the life of indigenous people, and influence on the rainfall regime.

Beside the physical difficulties, some institutional issues may open the door for conflicts in the Nile basin. At the basin level, there is no official comprehensive institutional guideline, framework or structure for river basin management as one unit. However, a number of treaties and agreements were held between some countries. Some of those treaties are subject to controversy due to the lack of support by new generations. Those treaties were negotiated and signed by colonial powers and, subsequently, represent their own interests and not necessarily those of --at that time-- occupied nations. After gaining their independence, those nations expressed their objections on several occasions. Of the well-known objections is the Nyerere Doctrine according to which neither Tanganyika, Uganda, nor Kenya recognize the 1959 Nile Waters Agreement.

Reluctantly, the Nile basin countries cooperated in the UNDP Hydromet project and participated in the UNDOGO.[3] Nonetheless, the twenty second century has started with activities to bring the Nile Basin countries to cooperate more closely in developing the Nile basin. In June 2001, the first meeting of the International Consortium for Cooperation on the Nile (ICCON) took place in Geneva and established partnerships that will lead to sustainable development and management of the River Nile for the benefit of all. ICCON1 will bring Ministers and senior officials from Nile basin countries together with a broad range of bilateral and multilateral donors and other interested parties, such as civil society, professional organizations, media and NGOs. After less than a year (in April 2002), the Nile Basin-Japan Ministerial Roundtable took place in Japan. It was hosted by the Third World Water Forum Secretariat (WWF3), and jointly sponsored by the WWF3 Secretariat and JICA. The World Bank and the Nile Secretariat were the co-conveners. The objectives were to: share experiences in key areas of river basin management, build relationships; and prepare for the major Nile Basin showcase at the WWF3 in Japan in March 2003.

The Nile revenue is 55.5 bcm according to the 1959 agreement. For modeling purposes, it is plausible to assume that the Nile revenue is fixed since water release is controlled by the High Aswan Dam. As such, the water stock in Lake Nasser can normally be used to offset the variation in flood revenue.

2.2 Aquifer Water

Total withdrawals from aquifer and groundwater in Egypt are estimated at 3.3 bcm/year (Hefny et al. 1993 and Khadam 2001). Another estimate is 5.4 bcm (CAPMAS 2001 and Abdel-Fattah et al. 2001). The latter estimate is in accord with detailed data.[4] It is assumed that the rate of extraction is the safe yield. So, groundwater and aquifers will continue to supply that quantity and quality of water until 2050.

The quantity of groundwater depends on aquifer boundaries, size, rate of discharge, depth of water, and rate of extraction. Three types of groundwater sources are recognized in Egypt. The first type is groundwater under the Valley and Delta soils. This is not a source in itself. Mainly, it is the seepage of the irrigation and drainage networks. The total amount in that store is 500 bcm. Annual replenishment is 8 bcm/year of which 3 bcm/year flow back to the Nile. Quality of water in that storage is suitable for irrigation (Hefny et al. 1993). An inventory made by the Groundwater Research Institute indicates that extraction in 1992 was 4.7 bcm (Yakoub 1995).

Another type is found at the fringes of the Valley and Delta. It is replenished by adjacent agriculture soil, occasional runoff, and adjacent carbonate rocks. Quality and quantity of that water depends on the type of irrigation and source of replenishment. Therefore, it is most appropriate for conjunctive use (Hefny et al. 1993).

The third type is the Nubian sandstone, which is one of the largest aquifer basins in the world. It is extending from north of the Sudan, Chad, eastern Libya, and Egypt's western desert where it is a main source of water. It is bounded from north by a saline freshwater interface (Ahmad 1993). The basin's area is about 2 million km^2; one third of which is in Egypt. It is recharged from the rainfall in the south west of Erdi-Ennedi-Tibesti mountains. Replenishment is not exactly known but one estimate is 3 bcm/year (Fayadd 1999). Estimates of water storage in that important aquifer vary significantly: 16,000 bcm (Khadam 2001); 200,000 bcm (Bayoumi et al. 1997); in addition to several other estimates (Ahmad 1993). Withdrawals are estimated at 400 mcm/year. The safe yield is estimated at 1 bcm/year for 50 years (Said 1993).

2.3 Rainwater

Rainfall is concentrated in the coastal areas where it reaches 200 mm/year. Total rainfall is about 15 bcm of which only 1.4 bcm is utilized in agriculture (Khadam 2001 and AOAD 1997). Another 1 bcm is expected to be harvested from flash floods in Sinai and the Red Sea areas (Attia et al. 1997). For modeling purposes, the quantity of rainwater utilized is assumed to be 1 bcm till 1999 then 2.4 bcm starting the year 2000 on the ground that rainwater harvest structures are installed by that time.

2.4 Desalination

With long shores along the Mediterranean and the Red Sea, in-land lakes and wetlands, desalination is a strategic water reserve for Egypt to meet municipal and industrial demands especially in coastal zones. Cost of desalination depends on the technology in use and on the salinity of the water source. Desalination of brackish water ranges from US$ 0.4-0.6/m^3; that of sea water is US$ 1.05-1.87

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[3] The ten countries are: Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda.

[4] Extraction in the Valley and Delta is 4.7 bcm + 0.48 bcm in the Western Desert (Bayoumi et al. 1997) + 0.09 bcm in Sinai (Bayoumi et al. 1997) = 5.27 bcm.

/m^3 (Sadik and Barghouti 1996). In 1996, the production of desalinated water was 32 mcm/year (ACSAD et al. 1997).

2.5 Wastewater Reuse

Wastewater comprises municipal effluent, industrial discharge, and agriculture drainage. The latter provides most of the quantity of wastewater. Part of the wastewater returns to the system because of the absence of drainage network. This part is used again in the system. It is estimated that naturally drained water is reused 2-4 times during the Nile trip from Aswan to the Mediterranean. This unique feature of the Egyptian water system enables Egypt to cultivate a cropping pattern that uses 60-80 bcm of irrigation water using 38 bcm as indicated in formal water balances (Allan 1996-b).

The quantity of drainage water is falling due to tightening the control over distribution and improving irrigation efficiency. In 1984-85, drainage water was estimated at 14.3 bcm dropped to 12 bcm in 1988-89 (Abu-Zeid and Abdel-Dayem 1993); it is about 33 percent of the applied irrigation water.

The quantity of water reuse varies significantly from one document to another. In upper Egypt, drainage water is reused indirectly. It returns to the Nile itself and gets reused indirectly downstream. This amount is estimated at 5.3 bcm. Reuse in the Delta during the period 1990-96 is estimated at 3.96 bcm, 0.23 bcm in Fayoum and 2.8 bcm unofficial reuse in the Delta region. As such, total reuse of drainage water is 12.3 bcm/year. Another source estimates reuse at 3.42 bcm in 1987/88 to reach 5.22 in 1990/90 but falls to 5.12 and 4.86 in 1991/92 and 1992/93 (Zhu et al. 1995). This source does not take into account indirect and unofficial uses.

Future plans are made to reuse additional 8 bcm. Average discharge to the sea and lakes from the Delta region and Fayoum during 1990-96 is 13 bcm (MPWWR 1997). Lower estimates are: about 4.5 bcm (Mansour et al. 2001 and CAPMAS 2001) and 7.6 bcm (AOAD 1997).

3. Theoritical Framework

The normative propositions of welfare economics underlie the analysis in this research: (a) each individual is the best judge of his/her own welfare, (b) the welfare of a society is based on the welfare of its individual citizens, (c) if the welfare of one individual increases and the welfare of no other individual decreases, the welfare of the society increases (Pareto improvement), and (d) when no increase in any individual's welfare is possible without diminishing satisfaction for some other person, then a Pareto optimum is reached. The major critique of welfare economics is that a potential Pareto improvement treats all affected individuals equally. Criteria based on this principle accept an action that makes the poor poorer and the rich richer. As such, efficient allocations are not necessarily fair and might be biased to the status quo. The principle adopted in this paper is that when the scarcity of a strategic resource like water is going to place severe constraints on economic development and growth, then economic efficiency becomes also a social objective (Young 1995).

The very nature of water requires special care in the analysis. Water is usually a liquid. It tends to flow, evaporate, and seep as it moves through the hydrologic cycle (fugitive resource). Furthermore, water is a nearly universal solvent, which creates an inexpensive capacity for absorbing, diluting and transporting wastes to less-adverse locations (solvent property). Besides, water mobility makes it a high-exclusion-cost resource: the exclusive property rights, which are the basis of a market or exchange economy are relatively difficult and expensive to establish and enforce.

People obtain many types of benefits from water resources. Benefits are classified into five groups: (1) commodity benefits, (2) waste assimilation benefits, (3) aesthetic and recreational values, (4) ecosystem preservation, and (5) social and cultural values. The first type of benefit raises demand for water as a commodity (for final consumption or as input to production). The other types of benefits raise demand for water as an amenity. In order to keep the scope of work manageable and due to the difference between the methodologies dealing with the two types of demands, this research pays attention to commodity benefits and demand for water as an intermediate good. Other environmental issues will be addressed in future research.

Economic agents whose behavior affects the demand for water are households, industrial firms and agriculture farms. Institutions governing water allocation and use are the backbone of the system. Only agriculture farming is considered in this work. Others are excluded by plausible assumptions. As such, this work is concerned with the first category of benefits; specifically, benefits in the form of production of more agriculture commodities *via* making more irrigation water available by reusing treated wastewater (agriculture drainage, municipal effluent, and industrial discharge).

Demand for irrigation water has several dimensions: spatial, temporal, quantity and quality dimension. The focus of this paper is on the quantity dimension. The interest in quantity emanates from the fact that the greater the quantity demanded, the greater the effluent that will be discharged. While greater water demand expands water deficit, reusing wastewater partly offsets that effect. Favorable environmental benefits will be associated with treating and reusing wastewater; yet estimating those benefits are beyond the scope of this paper.

Analysis covers agriculture commodities and physical inputs, services such as management, and resources of special nature; specifically, irrigation water. As for commodities and physical inputs, prices are obtained from records of observed markets prices. Keeping in mind the liberalization of the Egyptian economy, it is assumed that market prices reflect the appropriate value of the items of interest. Markets exist for agriculture managers, but unlike commodity markets, they are not competitive and there are no records to provide proper reflection of underlying preferences or costs. So, suitable adjustment has to be made (detailed below).

4. Model Structure

4.1 Data Sources

The research draws upon readily available databases, published and unpublished research, personal communication, specialized environmental agencies, and wastewater treatment plants.

Population data is obtained from the UN population prospects prepared by the Population Division, Department of Economic and Social Affairs. It provides four scenarios of population growth: high, medium, low and *status quo* variants. The first three are used in this study.

Agriculture data is obtained through the internet from FAO. The Food Balance Sheets, and Primary Crop Production tables are used extensively. The Food Balance Sheets are available from 1961 to 1999. They provide three main sets of data: domestic supply (which comprises local production, imports, change in stock and exports), domestic utilization (feed, seed, processing, waste and food), and per caput physical supply, calories, protein and fat. Data are provided for each food crop. Crops are grouped into categories such as cereals, starchy roots, sugar crops, oil crops, vegetables, fruits, pulses and meat. The database can provide food balances for each year or averages of a number of years. Research relied on average food balance sheets for the periods 1997-99, 1992-94 and 1961-63. Rate of consumption growth is obtained by comparing the food balance sheets of 1997-99 with 1961-63. The initial consumption values for food crops are obtained from 1992-94 food balance sheet.

Time series (1961-2000) of crop production are obtained from FAO Primary Crop Production tables. The forty year series is used to estimate the change in yield. The rate of change is applied to future yield in order to accommodate technical development (according to model assumptions). Cotton is not provided explicitly so it is substituted by the fibers data.

The Agriculture Economic Bulletin is used as a supplementary source and for verification purposes.[5] Data on water are obtained from a large number of international, regional and national sources.

4.2 Model Assumptions

4.2.1 Assumptions Related to Agriculture Area

In this context, distinction is made between two terms “agriculture land” and “the cultivated area”. Agriculture land is the physical cultivable area whether actually cultivated or not. Cultivated area is equal to or less than the agriculture land. It is determined by resource limitations (e.g. shortage in irrigation water) or policy intervention.

The area of the agriculture land is a positive function of the land reclamation program, and a negative function of the level of urban encroachment, skimming topsoil and desertification. Land reclamation is implemented according to the State plan. Over the period 1997-2017 (four five-year plans), the State is planning to reclaim 4.3 million acres (Fathallah et al. 1998 and GARPAD 1996). Annual loss of agriculture land is estimated to range form 15-30 thousand acres (EPIQ 1998 and Abdel Mageed 1996). Urban encroachment will continue because of the construction work associated with the implementation of rural development plans such as building schools, hospitals, water treatment plants and the like.

Given the State reclamation plan and the annual loss of agriculture land, the area of agriculture land is assumed to increase between 1995 to 2020. Afterwards it will stay constant. Tacitly, the increase during the first period implies that the area of newly reclaimed land is greater than that encroached or lost for desertification. After 2020 and until 2050, the area of the new land is exactly equal to that lost through urban encroachment. Thus, the net increment in the agriculture area is zero during the period 2020-2050. In other words, the agriculture area is constant during that period.

Also, it is assumed that a ceiling on the area of land to be cultivated can be successfully enforced as a policy intervention in response to water shortage (refer to the section on Policy Intervention).

4.2.2 Assumptions Related to the Cropping Pattern

The cropping pattern is heavily influenced by national policies seeking food self-sufficiency. The existing cropping pattern has high water requirement. Cereal crops, rice and sugarcane require large quantities of irrigation water (Abu Zeid and Rady 1992).

A number of representative crops constitute the cropping pattern understudy. Selection of representative crops are based on the following factors:

a) At least one crop is selected out of each food category as defined in FAO Food Balance Sheets.

b) Crops capture most of the nutrient content of the Egyptian population; and

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[5] Issued annually by the Ministry of Agriculture and Land Reclamation (MALR).

c) Altogether selected crops occupy most of the agricultural land.

The selected crops capture 77 percent of the calorie content and 80 percent of the protein content of the Egyptian population’s diet in 1997-1999. Furthermore, they occupy 98 percent and 70 percent of the total agricultural land cultivated in the winter and summer seasons of 1995, respectively. Of the cereals category, wheat, maize, and rice are selected. They capture 98 percent of the calories and the protein provided by cereals. Broad beans represent the pulses. Although only 5 percent of the calorie and the protein content of the consumed pulses are represented; it has the largest explicit contribution to the pulses diet. Tomatoes represent the vegetables and give 41 percent of the calories and 46 percent of the protein provided by vegetables. Tomatoes are classified by season as summer and winter tomatoes. Potatoes represent the starchy roots and supply 82 percent of the calories and 86 percent protein for starchy roots. Sugarcane is the main sugar crop. Citrus is taken to represent fruits (15 percent of the calories and 28 percent of the protein).[6] Sesame is selected from the oil crops group.

Beside the above food crops, cotton is selected as a fiber crop and long berseem as a green fodder. Since there is no data readily available on their consumption, the change in the area during the period of analysis is considered as a proxy of growth in consumption. Growth factors are provided in Table 1 along with other basic data.

ET_0[7] varies from a region to another within Egypt. For rice, ET_0 of the Delta agriculture region is adopted. This is where rice cultivation is concentrated. As for sugarcane, ET_0 of the Upper Egypt region, where sugarcane is mainly grown, is adopted. For the other crops ET_0 of Middle Egypt is taken as an approximation of all Egyptian regions. The values of ET_0 adopted in the model are provided in Table 1.

The cropping pattern of 1995 is proportionately adjusted to occupy the entire agriculture land area (Table 2). It is adjusted by raising the actual crop areas proportionately so as to use up all the available agriculture land.

4.2.3 Assumptions Related to Yield

Technology change is allowed by changing yield over time. Change in yield is a proxy of the effect of technological development on productivity. Yield growth is assumed to follow a natural growth pattern assumed to prevail over the past forty years (1961-2000). The natural growth formula is derived in Box 1.

Box 1: Derivation of the Natural Growth Formula

$Y=Ae^{rt}$; *where Y is yield at year n, A is yield at time n-1, r is the rate of growth, and t is time which is 1 in this case. Taking the natural log of both sides (Chiang 1984)*

$$\ln Y = \ln A + rt \ln e$$

$$r = (\ln Y - \ln A)/t; \qquad \ln e = 1$$

The recent history indicates that the Green Revolution has had a tremendous positive effect on food security. Presently, technological advances pave the way for an increase in yield, these include: growing integration of the world food markets, less preoccupation of decision makers with food self-sufficiency issues, and expanding removal of price distortions (Pingali and Rajaram 1998).

Possible revolutionary achievements are not accommodated in this model. An example of such an achievement is genetically modified crops, which though promising, are not globally acceptable yet. While some countries like USA, Argentina and Canada have been widely planting genetically modified cotton, maize, and soybeans with favorable reduction in production costs, most other countries do not permit the cultivation of genetically modified crops because of deficient capacity to test biosafety, media opposition, or anxiety regarding consumer acceptance of such products (Paarlberg 2001). Nonetheless, it is believed that with proper biosafety precautions, genetic modification will not be riskier than conventional breeding methods (Pinstrup-Anderson and Schioler 2001).

The yield of new land is assumed equal to that of the old land. To evaluate the implication of that assumption: the yield of new lands in 1992 for wheat, barley, maize and peanuts is estimated at 8.01, 4.98, 14.5 and 11.35 ardabs/acre. The corresponding yield in the old land is 15.86, 11.96, 18.45 and 13.1 ardabs/acre (Abdel-Fattah et al. 2001). Thus, the yield of the new land ranges from about 40-90 percent of that of the old land. In spite of the significant difference between the yield of the old and new lands, the effect of the assumption on the results is negligible due to the relatively small weight of the area of the new land added annually to the agriculture area (less than 1 percent). Over time, the new-land yield approaches that of the old land as soil quality improves.

The initial yield is the values of the average of 1992-94. This assures the consistency with the latest actual population size of 1995 (Table 1).

4.2.4 Assumptions Related to Consumption

For all developing countries combined per capita consumption of different animal meat, poultry, eggs and milk increased by an average of 50 percent per person between 1973 and 1996 (Fritschel and Mohan 1999). Along the same

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[6] Dates share in calories exceeds that of citrus (33 percent) but its share in the protein is less (22 percent).

[7] ET_0 is the evapotranspiration of crops which is measured in m^3/ achre

trend, most of the increase in world food demand will take place in developing countries (Pinstrup-Andersen et al. 1999).

- Future changes in consumption are assumed to follow previous years (1961-2000) as traced by the natural growth model (Box 1).
- Tastes and preferences are held constant. People continue using the same consumption bundle to get their calorie and protein needs. Nonetheless, consumption levels may increase or decease over time according to the trend shown by the FAO Food Balance Sheets.
- FAO definition of per caput consumption had to be modified. In FAO Food Balance Sheets, per caput consumption is calculated by dividing the local production by the population size. This ignores exports, imports, and change in commodity stock all of which are part of consumption at large. In fact, the quantity available for consumption is local production less exports plus imports and stock change; altogether termed “domestic supply”. It is found that for the purposes of this work per caput domestic supply represents consumption better.
- A reservation on consumption assumption is the misleading effect of food subsidies. In Egypt, food subsidies represented 5.6 percent of government expenditures in 1996/97 amounting to LE 3.7 billion. Subsidy is directed mainly to popular (“baladi”) bread (57 percent of its price), wheat flour (43 percent), sugar (43-62 percent), and edible oil (42-54 percent) (Ahmad et al. 2001). Food subsidy conceals the real demand for food items when consumers face actual market prices instead of subsidized prices.
- The initial consumption is represented by the values of the average Food Balance Sheet of 1992-94. This assures the consistency with the latest actual population size 1995 (Table 1).[8]

4.2.5 Assumptions Related to Water

- Water is dealt with as an intermediate good to agriculture production, specifically, irrigation.
- For modeling purposes, aquifer and groundwater extraction is estimated at 5.4 bcm.
- Municipal use takes top priority in water allocation followed by industrial demand. Needless to say, the priority given to municipal use is due to its vital role in life sustenance and in maintaining fair hygienic standards. As for the industrial sector, it yields faster growth, creates a greater number of jobs and generates higher value added per unit of water than would a crop production enterprise (Allan 1996; Young 1995; and Young et al. 1972). Besides, the agriculture sector can substitute for water shortage by importing virtual water from international markets (in the form of agriculture products).
- No special release will be made for the generation of hydroelectric power and navigation.

4.3 System Structure

The population-water-food system is broken down to its key components. The principal relationships among system components are identified. Then, the dynamics of the whole complexity is simulated using STELLA™ software. The model’ logical structure is sketched in Figure 1. It comprises 3 main parts:

(1) The system's relationships (Section 4.3.1 below). They are grouped in the following submodels (sectors in STELLA terminology):

- Population Submodel
- Food Consumption Submodel
- Food Production Submodel
- Water Supply-Demand Submodel
- Economics Submodel

Population growth plays a central role in the model. It is the variable that triggers the whole process of actions and interactions. Paradoxically, while population growth requires more food consumption (Figure 1), it adversely affects the availability of water for irrigation. For population growth is the principal variable behind the rise in municipal water demand. Furthermore, in conjunction with economic growth, population is behind the increase in industrial demand for water. Since available water tends to be rather rigid, it is subject to a zero-sum game. The increase in municipal and industrial needs comes at the account of the water available for irrigation and, subsequently, for local food production, assuming no change in technology that would affect water requirement (in quantity and quality). The drop in the quantity of water available for irrigation will force some cultivatable area out of production.

Comparing food consumption with production reveals the status of the food balance. Food deficit is imported and food surplus is exported. This reflects on the system’s economics. Furthermore, water balance is related to the system’s economics through the net return to water used in irrigation and the costs and benefits of treating and reusing wastewater.

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[8] Rice needs are provided in milled equivalent. It is divided by 0.65 to convert it to paddy rice (Hazell et al. 1994).

(2) A set of policy intervention tools (Section 4.3.2 below) used to adjust the food production system in response to water shortage. Intervention tools comprise:

- Cultivable-Area intervention tool, which forces an upper bound on the cultivable area proportional to the water deficit.
- Cropping-Pattern intervention tool, which confines the cropping pattern to crops with greater return water.
- Water-Reuse tool, which allows the reuse of drainage water to alleviate water shortage.

(3) A set of performance indicators are adopted to assess the system performance under different simulation scenarios (Section 4.3.3 below):

- Quantity of water available for irrigation
- Water balance
- Irrigation demand
- Cultivated area
- Total return to water
- Return to a unit of water

For the purposes of comparative analysis, policy tools are simulated under two different modes: "Land-First" and "Water First" modes. Under the *"Land-First" mode*, land is allocated to cropping activities first; water is allocated subsequently. It simulates the real life situation of resource allocation where farmers decide on distribution of their land resources (the resource under their full direct command), then they allocate the irrigation water they succeed in appropriating among the cultivated crops.

In the *"Water-First" mode* the quantity of water available for irrigation is determined first, then land is allocated subsequently. In other words, farmers are partners with the irrigation authorities in the decision making process. That way, not only farmland is under the full direct control of the farmers, but they have a voice in the allocation of irrigation water as well.

The principal model equations are explained below. They are shown in boxes. In each box, equations are arranged according to the order of execution. Variables are scalars, vectors or matrices. The dimensions of the vectors or matrices are written within braces with CROPS=12 crops selected for the study and VARIANT=3 population variants. Additionally, all variables are dimensioned to the time duration of the analysis: t=56 years from 1995 to 2050.

4.3.1 System's Relationships

4.3.1.1 Population Submodel

The Population submodel traces population growth during the period of analysis. Three variants of population growth are used: high, medium and low variants. Output of the population submodel feeds into two submodels: the Food Consumption Sub model to estimate the national food needs and the Water Resources Submodel to estimate municipal water use.

Box 2: Population Growth

Population Stock[VARIANT](t) = Population Stock[VARIANT](t - dt) + (POPULATIONS[VARIANT] - Pop_Variants[VARIANT]) * dt

As indicated in Box 2, the population size at a point of time {Population_Stock[VARIANT](t)} is equal to the population size at previous point of time {Population_Stock[VARIANT](t-dt)} plus the increase in population {(POPULATIONS[VARIANT]-Pop_Variants[VARIANT])} during the time increment {dt}.

4.3.1.2 Food Consumption Submodel

Starting with initial consumption {Initial_Cons[CROPS]}, consumption {Consumption[CROPS,VARIANT]} is allowed to change over time by a factor {Growing_Cons[CROPS]} generated by the function EXP(.) without the lower or upper bounds and according to population size {POPULATIONS[VARIANT]}.[9]

Box 3: Food Consumption System [10]

Initial_Cons[CROPS] = *value*[CROPS]
Growing_Cons[CROPS] = Initial_Cons[CROPS]*EXP(Consumption_GF[CROPS])
Consumption_GF[CROPS] = CGROWTH(*growth factor*)
Consumption[CROPS,VARIANT] = Growing_Cons[CROPS]*POPULATIONS[VARIANT]/1000
Food_Balance[CROPS,VARIANT]=Food_Prod[CROPS,VARIANT]-Consumption[CROPS,VARIANT]

---

[9] The function EXP(.) gives "e" raised to the power of expression (HPS 1997).

[10] Per caput domestic supply is in kg/caput/year, multiplied by population in thousands results in thousands of kg/year or; equivalently, mt/year which is divided by 1000 to get thousand mt/year.

The food balance {Food_Balance[CROPS,VARIANT]} is estimated by subtracting consumption from food production {Food_Prod [CROPS,VARIANT]}, which is estimated in the Food Production Submodel.

4.3.1.3 Food Production Submodel

The Food Production Submodel is responsible for the allocation of the agriculture land, determination of irrigation needs, and estimation of the local production of the selected crops. Also, it passes irrigation requirement to the Water Supply-Demand Submodel in order to estimate the water balance. Similarly, it sends data to the Economics Submodel to estimate farm accounts.

Main equations pertaining to the determination of the agriculture land are introduced in Box 4. It captures the dynamics of the area of the agriculture land along with necessary adjustments during the period of analysis. As mentioned above the change in the agriculture area takes place as a result of the land reclamation program and/or different types of encroachment. Policy intervention may lead to the cultivation of an area less than the agriculture land. Agriculture area is presented by {L_Stock[VARIANT](t)}. Area to be cultivated is presented by two variables: {Ag_L_Area[VARIANT]} and {AG_AREA[VARIANT]}; the reason for presenting it by two variables is to avoid circular calculation. The initial agriculture area {INITL_Stock [VARIANT]} is estimated in 1995 at about 8 million acres (FAO, Land Use). The possible change in agriculture area is captured by {AREA_CHANGE [VARIANT]} (presented below).

Box 4: Determination of Agriculture Area

```
INIT L_Stock[VARIANT] = 7812.7
Ag_L_Area[VARIANT] =
AREA_CHANGE[VARIANT]+L_Stock[VARIANT]
AG_AREA[VARIANT] = L_Stock[VARIANT]
L_Stock[VARIANT](t) = L_Stock[VARIANT](t -dt) +
   (Ag_L_Area[VARIANT] - AG_AREA[VARIANT]) * dt
```

The agriculture area is allocated among cropping activities according to the equation {LAND_ALLOCATION[CROPS,VARIANT]}. First, the agriculture area {AG_AREA[VARIANT]} is multiplied by the {LAND_FIRST} switch. It takes the value of 1 (ON) in order for the “Land-First” strategy to prevail; else, it is zero. Second, the {ADJUST_LAND[VARIANT]} is added; the value of this variable is zero except when the “Water-First” strategy is in effect. Third, output of term {(AG_AREA[VARIANT]*LAND_FIRST)+ ADJUST_LAND[VARIANT]} is multiplied by {Combined_Area_F&GF [CROPS]} which comprises the time-trend of the area of each crop over the period 1960-2000 {Area_GF[CROP]} and crop land share {Initial_Area_Factor[CROPS]}.

Box 5 explains the way the model allocates land over crops. The first equation the {Area_GF[CROP]} is the natural change in a crop area according to the formula in Box 1 above with the values provided in column 2 in Table 1.

Box 5: Allocation of the Agriculture Area

```
LAND_ALLOCATION[CROPS,VARIANT] =
   (((AG_AREA[VARIANT]*LAND_FIRST) +
   ADJUST_LAND[VARIANT])*Combined_Area_F&GF[CROP
   S])-Adj_CP[CROPS,VARIANT]
Area_GF[CROP] = CGROWTH(value)
Acumulate_GF[CROPS] =
Initial_Area_Factor[CROPS]*EXP(Area_GF[CROPS])
```

The second term is the {Acumulate_GF[CROPS]} starting with the area factor at the beginning of the period { Initial_Area_Factor[CROPS]} and calculates the growth factor for each crop over the time period using the function {EXP(.)}

Starting by initial yield {INIT Yield[CROP]} (Box 6), yield {Yield_Growth[CROPS]} is allowed to grow over time according to the growth factors {Yield_GF[CROP]}.

Box 6: Yield Projection System

```
INIT Yield[CROP] = value
Yield_Growth[CROPS] =
Yield[CROPS]*EXP(Yield_GF[CROPS])
Yield_GF[CROP] = CGROWTH(value)
```

Local food production {Food_Prod[CROPS,VARIANT]} is the product of multiplying yield {Yield[CROPS]} by the corresponding crop area {LAND_ALLOCATION[CROPS,VARIANT]} (Box 7).

Box 7: Food Production System

```
Food_Prod[CROPS,VARIANT]=Yield[CROPS]*LAND_ALLOC
ATION[CROPS,VARIANT]
```

The last part in this submodel estimates the quantity of water required for cultivation. Water required to irrigate each crop {Irrigation_Needs [CROPS,VARIANT]} is reached by multiplying a crop evapotranspiration {ET_0[CROPS]} times the corresponding area {LAND_ALLOCATION [CROPS,VARIANT]} then summing up over crops gives total irrigation needs {SUM_IRR_NEEDS[VARIANT]} (Box 7).

Box 8: Irrigation Water System[11]

ETo[CROP] = *value*
Irrigation_Needs[CROPS,VARIANT] = ET_0 [CROPS] *
LAND_ALLOCATION[CROPS,VARIANT] / 1,000,000
SUM_IRR_NEEDS[VARIANT] =
ARRAYSUM(Irrigation_Needs[*,VARIANT]

The output of the Food Production Submodel is sent to the Food Consumption Submodel in order to construct a food balance. Also, it is passed to the Economics Submodel to calculate farm accounts and return to water. Additionally, it feeds the Cropping Pattern Switch, the Cultivable Area Switch, and the Water-First Switch all of which are discussed below.

4.3.1.4 Water Supply-Demand Submodel

One of the objectives of this submodel is to estimate the quantity of water available for irrigation and to construct a water balance. Freshwater supply comes mainly from the Nile {Nile} plus modest amounts of rain {Rain} and aquifer {Aquifer} water. These sources are supported by reusing discharged water {Reuse}. These quantities are assumed to be fixed.

As for withdrawals, municipal water is rising due to population growth, rise in income, and expansion of water services to disadvantageous areas. In 1995, municipal water was about 5 bcm; a lower estimate is 3.8 bcm of which about 60 percent is the effluent (Said 1993). The lower estimate is based on 200 lpd; but per capita daily use in 1990 is estimated at 235 lpd (Mankarious and El-Shibiny 1992). The comparison supports the higher estimate of municipal use (5 bcm). Municipal needs are expected to increase to: 12 bcm in the case of high population growth variant (average natural rate of growth of 1.4 percent), 10 bcm for the medium population growth variant (average rate of 1 percent), and 8 bcm for the low population growth variant (average rate of 0.7 percent).

Municipal water vector {DRINK[VARIANT]} is dimensioned by population variants.[12] It is calculated by multiplying each variant by the average daily drinking water per person of 1990 {water_lpd}. To get annual drinking needs, the daily population needs is multiplied by 365 days. This rate is assumed to stay fixed over the period of analysis. Any increase in population needs during that period is met by improving the already low network efficiency.

The waste in treated water is as high as 74 percent as compared with the internationally acceptable level of 25 percent. Waste comprises three categories: production waste, network waste, and consumption waste. The production waste is the difference between the raw water coming into the treatment plant and its output; it is estimated at 35 percent compared to the international mark of 6 percent. Network waste is the difference between the quantity of water at the net starting and ending points; it is estimated at 50 percent while the international standard is 12 percent. The last category is consumption waste, which is the difference between what enters a building and the discharge (net of real consumption); it is about 20 percent while the international level is 10 percent (Al-Basel 2001).

Industrial need {Industry} is presented as a function of time and is based on 1995/96 estimates (Attia et al. 1997). It is allowed to increase from 1995 to reach its maximum in 2020; it stays at that level to the end.

Because the model simulates 3 population growth variants and since municipal water is population dependent, the model includes three variants of municipal water needs. And subsequently, three variants of available irrigation water and three variants of water balance.

Municipal and industrial uses are assumed to have first priority in the allocation of fresh water. Deficit is shifted to the agriculture sector since shortage can be offset by importing the virtual water available in the international market. Evaporation from water ways is accounted for as a withdrawal {Evaporation".[13] It is assumed constant at 2 bcm/year (Abu Zeid & Raddy 1991).

Box 9: Estimation of the Quantity of Water Available for Arrigation

Fresh_Water(t) = (Nile + Rain + Aquifer + Reuse - Industry -
Evaporation - Sea - Remainder) * dt
Nile = 55.5
Rain = 1

---

[11] ET_0 in m^3/acre times crop area in thousand acres gives thus and m^3 divided by 1,000,000 to get bcm.

[12] Population_Variants[VARIANT] in thousand * water_lpd in liter/person/day = thousand liter /day or m3/day*365 = m^3/year/ 1,000,000,000 = bcm/year.

[13] This does not include evaporation from Nasser Lake (an average of 10 bcm/year). It is taken into consideration before allocating Egypt's share of the Nile water.

```
Aquifer = 0.6
Reuse = 12.6
Industry = GRAPH(TIME)
Evaporation = 2
Sea = 13.05

DRINK[VARIANT] =
POPULATIONS[VARIANT]*water_lpd*365/1,000,000,000
water_lpd = 235
Remainder = Fresh_Water+TREATED_WATER
AVAILABLE_FOR_IR[VARIANT] = Remainder-
DRINK[VARIANT]

WATER_BALANCE[VARIANT]=AVAILABLE_FOR_IR[VARI
ANT]-SUM_IRR_NEEDS[VARIANT]
```

Water available for irrigation {AVAILABLE_FOR_IR[VARIANT]} is reached by subtracting withdrawals and drinking from total water supply. Water available for irrigation may be supported by treating discharged water {TREATED_WATER} as discussed under the Water Reuse Switch. To estimate water shortage or surplus, total irrigation is compared with the quantity available for irrigation {WATER_BALANCE[VARIANT]}.

4.3.1.5 Economics Submodel

A number of indicators are estimated by the Economics Submodel: return to a cubic meter of irrigation water for each crop {RETURN_TO_WATER [CROPS]}, and the sum of return to irrigation water {SUM_R_TO_W [VARIANT]}, and return to all quantities of water used to irrigate each crop {Total_R_to_W[CROPS,VARIANT]}. Estimation of these indicators is made utilizing the imputed cost method. Accordingly, farm accounts of all explicit and implicit revenues and costs are considered. Revenues {Revenues[CROPS]" comprise both main- {Yield[CROPS]*Output_Price [CROPS]} and by-products {ByYield[CROPS]*ByPrice[CROPS]}. Cost includes material inputs {Direct_Cost[CROPS]" such as fertilizers and chemicals, services like land preparation, implicit values such as the opportunity cost of working capital and rewarding management efforts. Return to land is taken as equal to rent since the agriculture input markets in Egypt has been freed; so is the relationship between land owners and tenants. The set of equations of this submodel is presented in Box 8.

The Economic Submodel also calculates the per-unit benefit of treated water {Unit_Benefit[VARIANT]" by dividing return to irrigation water by its amount. Then, the per-unit cost of treatment {Unit_Treat_C} is estimated using the data of an Australian treatment plant. The benefit {Treat_B[VARIANT]" and cost {Treat_Cost" of treating water are calculated using per-unit estimates. Net benefits {Net_B[VARIANT]}, of course, are the difference between benefits and costs.

4.3.2 Policy Intervention Tools

Provided that water shortage is inevitable and that it will be increasing over time, it is deemed necessary to consider a number of ways that enable policy makers to effectively intervene for the purpose of inducing behavioral changes that lead to slowing down the water deficit. Policy tools are introduced below. Each tool is presented in a submodel. A policy intervention is activated by a switch with binary values: 1 if the switch is "ON" and zero if the switch is "OFF". If the value of a switch is 1, then the policy is in effect; otherwise it is not operation. Policy intervention comprises:

- Putting a limit on the area to be cultivated (Cultivable Area Tool).
- Eliminating crops that generate relatively low return to water (termed Cropping Pattern Tool).
- Water Reuse Tool.
- Water-First Mode.

4.3.2.1 Cultivable Area Tool

Determination of cultivable area is one of the policy tools in this model. The idea is that if water shortage prevails, then there is no point in reclaiming land or even cultivating the same area of the old land. Such adjustment protects short- and long-term investments. The land reclamation plan {Reclaim_Plan} is a function of time: 75 thousand acres are to be reclaimed annually between 1995 and 2020. This adds up to about 1.6 million acres.

Box 10: Economics Submodel

```
Gross_Margin[CROPS](t) = (Revenues[CROPS] -
    Direct_Cost[CROPS]) * dt
Revenues[CROPS] =
(Yield[CROPS]*Output_Price[CROPS])+(ByYield[CROPS]*ByPr
ice[CROPS]
Direct_Cost[CROPS] = VC_AgOper'n[CROPS]+
    VCFert&Lab[CROPS]+ VCHarvest[CROPS]+
    VCIrrigate[CROPS]+VCLand_Prep[CROPS]+VCMisc[CROPS
```

]+VCPest[CROPS]+VCS'd&C'vation[CROPS]+VCTransport[CROPS]+VCUnaccounted[CROPS]

Capital = *value*

RETURN_TO_WATER[CROPS] = (Gross_Margin[CROPS]-(Capital*Direct_Cost[CROPS])-Management[CROPS]-Rent[CROPS])/ETo[CROPS]

SUM_R_TO_W[VARIANT] = ARRAYSUM(Total_R_to_W[*,VARIANT])

Total_R_to_W[CROPS,VARIANT] = (RETURN_TO_WATER[CROPS]* LAND_ALLOCATION[CROPS,VARIANT])/1000[14]

Unit_Benefit[VARIANT] = (SUM_R_TO_W[VARIANT]/(SUM_IRR_NEEDS[VARIANT]-ABS(WATER_BALANCE[VARIANT])))/1000[15]

Net_B[VARIANT] = Treat_B[VARIANT]-Treat_Cost

Treat_B[VARIANT] = TREATED_WATER*Unit_Benefit[VARIANT]*1000/1,000,000

Treat_Cost = TREATED_WATER*1000*Unit_Treat_C/1,000,000[16]

Unit_Treat_C = *value*

The {ADJUST_AREA} is a switch that takes a binary value either 1 (if the switch is On) or 0 (if the switch is Off) (Box 9). The output of the logical variable that evaluates the water balance {WATER_BALANCE[VARIANT]}. The logical variable {Adj_Area[VARIANT]} tests the water budget: if a water surplus is recognized then the reclamation plan continues. In this case, its value is passed to {Land Change} in the Food Production Submodel (Box 3). Otherwise it is adjusted proportionately. If a deficit persists, then deficit is converted by a converging factor to a land area equivalent to the water deficit and subtracted from the {Reclaim_Plan}.

Box 11: Adjustment of cultivable area submodel

ADJUST_AREA = { 0 *if Off*
{ 1 *if On*

AREA_CHANGE[VARIANT] = IF(WATER_BALANCE[VARIANT]>=0) THEN(Reclaim_Plan) ELSE(Reclaim_Plan+(WATER_BALANCE[VARIANT]*1000/30))*ADJUST_AREA

Reclaim_Plan = GRAPH(TIME)

4.3.2.2 Cropping Pattern Tool

Adjustment of cropping pattern is another policy tool. Adjustment is guided by the return to water. The logical variable {Crop_YN[CROPS,VARIANT]} tests if a cropping activity generates unacceptable return to water, then it calculates its area {Shadow_Crop_Area[CROPS,VARIANT]} (Box 10). If a cropping activity yields a satisfactory return to water, the {Shadow_Crop_Area[CROPS,VARIANT]} is set equal to zero. The calculation of {Shadow_Crop_Area[CROPS,VARIANT]} is identical to that followed in the Food Production Submodel. The switch is operational if the binary variable {ADJUST_CP} is equal to 1; if equal to zero the submodel is not effective. This is done *via* the variable {Adj_CP[CROPS,VARIANT]} which multiply the logical variable {Crop_YN[CROPS,VARIANT]} by the binary variable {ADJUST_CP}.

4.3.2.3 Water Reuse Tool

The switch allows reusing drainage water to alleviate the water gap. Treating water for reuse is an option, which is applied in some of the simulation runs. The amount of water that can be treated is governed by technical considerations most notably discharging amounts large enough to protect the north delta from salt water intrusion and enough to leach the delta. Discharged water of reasonable quality is already in use after mixing it with fresh water. It is planned to reuse up to an additional 9 bcm of drainage water.

Box 12: Adjustment of Cropping Pattern Submodel

ADJUST_CP = { 0 *if Off*
{ 1 *if On*

Crop_YN[CROPS,VARIANT] = IF(RETURN_TO_WATER[CROPS]<0.5) THEN

---

[14] Return_to_Water[CROPS] is in LE/acre * Land_to_Crops[CROPS,VARIANT] in thousand acres = thousand LE /1000 = million LE.

[15] (Sum_R_to_W is in million LE / (Total_Irr_Needs in bcm - Hi_Water_Balance in bcm)) million LE divided by bcm gives LE/thousand m3 divide by 1000 = LE/mcm which is comparable with treatment cost (LE/million m^3).

[16] Treat_YN in bcm*1000 gives mcm*Unit_Treat_C in LE/mcm gives LE/1,000,000 gives million LE.

Shadow_Crop_Area[CROPS,VARIANT] ELSE
(Shadow_Crop_Area[CROPS,VARIANT]=0)
Shadow_Crop_Area[CROPS,VARIANT]=
AG_AREA[VARIANT]*Combined_Area_F&GF[CROPS]
Adj_CP[CROPS,VARIANT] =
Crop_YN[CROPS,VARIANT]*ADJUST_CP

In this model, discharged water has to receive tertiary treatment before its reuse in irrigation. This process starts in the year 2005 when the first sign of water shortage is recognized by the model. 1 bcm of discharged water will be treated every year until the cumulative total reaches 9 bcm. As such, water treatment {To_Treat} is a function of time. {TREATED_WATER} is utilized only if the submodel is operative; this is controlled by the binary variable {REUSE_W}. It takes the value of 1 when the submodel is operative; otherwise zero.

Box 13: Water Reuse Submodel.

REUSE_W = { 0 *if Off*
{ 1 *if On*
To_Treat = GRAPH(TIME)
TREATED_WATER = Treat*REUSE_W

4.3.2.4 Water-first Mode

In centralized water allocation, a water authority faces, and get affected by, a phenomenon known as the “tyranny of the small” (Kahn 1989). A huge number of farmers allocate their land resources first according to some objective function. A water authority has to serve those farmers. It does not have the means to communicate with them about availability of irrigation water, the suitable areas to be cultivated or left fallow in each season and which crops are to be cultivated (Box 12).

Box 14: Water-First Submodel[17]

WATER_FIRST = { 0 *if Off*
{ 1 *if On*
Crop_No = *value*
Sum_ET_0 = ARRAYSUM(ET_0[*])
Average_ET_0 = (Sum_ET_0/Crop_No)

ADJUST_LAND[VARIANT] =
AVAILABLE_FOR_IR[VARIANT] * 1,000,000 *
WATER_FIRST / Average_ET_0

This policy tool determines the agriculture land to be cultivated in light of the quantity of water expected to be available for irrigation. Approximately, the area to be cultivated {ADJUST_LAND[VARIANT]} is obtained by dividing the quantity of water available for irrigation {AVAILABLE_FOR_IR [VARIANT]} by the average evapotranspiration {Average_ET_0}. The latter is the quotient of dividing the sum of evapotranspiration of crops {Sum_ET_0} by the number of crops under study {Crop_No}. Policy intervention takes place when the switch variable "WATER_FIRST" is on; i.e. taking the value 1.

4.3.3 Model Indicators

Various simulation runs are assessed in the light of a set of indicators generated by the model:

- The quantity of water available for irrigation (For Irrigation in Figure 1).
- The water balance.
- The total irrigation needs.
- The cultivated area.
- The total return to water.
- Return to a unit of water (Return/m^3).

5. Simulation Results

Eight simulation runs are made to evaluate the effectiveness of four policy intervention tools under two simulation modes: Land-First and Water-First modes. These scenarios are summarized in table 4.

Only Scenarios C of the Land-First Scenarios and all the Water-First Scenarios generated favorable water balances; meaning that these policy intervention tools succeeded in dealing with water deficit. Nevertheless, further ranking is made in light of other criteria.

As mentioned above, population growth is assumed to be the trigger of all the actions and interactions in the model. Population projection of some selected years is provided in Figure 5. The high population growth variant assumes that no change in the present population growth pattern will take place until 2050. Accordingly, the Egyptian population will reach 97 million by 2020 and 142 million in 2050. The low variant assumes that efforts to control population

---

[17] "AVAILABLE_FOR_IR[VARIANTS]" is in bcm / "Average_ET0[VARIANTS]" in m^3/acre = billion acre* 1,000,000 = thousand acres.

growth succeed. The Egyptian population optimistically reaches 85 million in 2020 and 93 million in 2050 (less than the high variant population in 2020). The medium variant holds a middle ground: population grows to 91 and 116 million in 2020 and 2050.

Population growth underlies growing demand for water. Coupled with a fixed water supply, rising demand reduces water availability for irrigation. Industrial demand for water keeps increasing from 7.5 bcm in 1995 until it settles at 15.4 starting 2020. Evaporation and discharge to the sea are fixed at 2 and 13 bcm/year; in order. As such water uses (other than municipal use) range from 22.6 bcm in 1995 to 30.5 bcm in 2020 and stay at that value. Water supply stays constant at 69.7 bcm/year (55.5 Nile revenue, 1 use of rain fall, 0.6 aquifer water, and 12.6 water reuse). The remainder of the water (ranging from 47 to 39 bcm) is available for municipal use and irrigation.

The competition between demand for direct consumption (municipal use) and indirect use (to produce food) is the dilemma facing decision makers. The solution is that *"Throughout the world, national economies ... adjusted remarkably well to meeting their water resource needs ... through internationally available water"* (Allan 1996).

Municipal use starts at about 5.4 bcm in 1995 to reach 12, 10 and 8 bcm in 2050 for high, medium and low population growth variants, respectively. Because of the inverse relationship between municipal use and water availability for irrigation, the quantity of water available for irrigation in 1995 starts at 41.7 bcm and shrinks to 35, 37 and 39 bcm in 2050 for high, medium and low population growth variants, respectively.

Except for the quantity of water available for irrigation, all the above figures do not change from one scenario to another. Only water availability for irrigation changes as a result of policy intervention.

Scenario B introduces a control over the cultivable area in response to shortage in irrigation water, in spite of the increasing needs for food production. At the beginning of the period (1995), the cultivable area is 7.8 million acres. It keeps increasing until it reaches its maximum (about 8.5 million acres) in 2007 or 2008 depending on the population growth variant. Afterwards, the cultivated area shrinks year after another until it reaches 5.6, 6 and 6.3 million acres in 2050 for high, medium and low growth variants, respectively. The cropped area follows the same pattern: it starts at 13.3 million acres and reaches its maximum about 2007 (14.5 million acres) then declines to 10.2 million acres in 2050.

Figure 4 shows the effect of various policy intervention tools on the cultivable area. The initial cultivable area is 7.8 million acres. In Scenario A, it reaches its maximum of 8.3 million acres in 2002. Scenario D generates an impact like that of Scenario A: it reaches its maximum 5 years after Scenario A and at 75 thousand acres higher. Because the difference is too small to show on the graph, scenarios A and D are combined together. Scenario D did not make a significant difference over A because additional treated water can only bring limited areas of land under production. With the emergence of water shortage, the scenario treats and injects 1 bcm of water starting 2005. This continues until all attainable wastewater (9 bcm) is reclaimed by 2013, and this amount continues till 2050. Treated water ameliorates the water deficit problem but is not a cure.

Scenario C yields better results. It controls the cropping pattern in response to water shortage by eliminating the crops that do not generate a positive economic return to water. The cultivable area settles at a maximum of 9.5 million acres starting 2020. Unlike Scenarios A, B, D, F, G, which adopt the *status quo* cropping pattern, Scenarios C and H adjust the cropping pattern in response to water shortage. Only, berseem, winter and summer potatoes, winter tomatoes and broad beans are cultivated. Other crops are eliminated.

Like Scenario C, all scenarios of the Water-First mode have a favorable effect on the cultivable area. For, these scenarios adjust the cultivated area in response to water shortage.

Under the Land-First mode, Scenario B allows the adjustment of the cultivable area in response to the water shortage with a time lag. In that, water shortage is recognized first then the cultivable area is slashed down. The interaction of these two indicators is demonstrated in Figure 5. The upper panel shows the deteriorating water balance. At the beginning there was a declining water surplus until 2001 when water deficit is recognized for the first time. Water shortage reaches its peak (5.5 bcm) in the year 2019. Afterwards, water shortage starts improving. The lower panel shows the development of the cultivable area. To some extent, it is a mirror image of the water balance curve. It keeps increasing at a smooth rate from 7.8 million acres until it reaches its maximum of 8.5 million acres in the year 2008. Then, it keeps falling to slightly less than 6 million acres in 2050. Controlling the cultivated area improves the water balance.

Out of the eight scenarios, only two gave the higher return to water: Scenario C under Land-First mode and Scenario H under the Water-First mode. As pointed out above, both scenarios eliminate cropping activities not economically rewarding.

In terms of net food bill, Scenarios B, F, G, I generate negative food bills; meaning heavier reliance on food imports than in scenarios A, D, C, and H with C and H at a better ranking than A and D.

6. Conclusions

The model shows the impact of population growth. It leads to conflict between satisfying two basic needs: more water for direct consumption (drinking) and more water for indirect consumption (to produce more food). Although, states overcome shortage in irrigation water and, subsequently, food by importing virtual water, a growing shortage of irrigation water poses a threat to investments in irrigated agriculture. So, facing the situation by importing virtual water from the international market is not a sustainable strategy. Safely, it can be claimed that this conclusion is applicable to arid and semi-arid economies at large.

This research demonstrates that proper policy intervention succeeds in ameliorating the deteriorating situation. Furthermore, soft policy tools are more effective than structural works such as those involved in treating and reusing wastewater in curbing growing water deficit. To be more specific, policy tools based on economic criteria are the most effective in dealing with water shortage. For, in economies suffering water stress, economic and social efficiency of the allocation of that resource become one and the same. No wonder then that dedicating scarce irrigation water to cropping activities that generate the highest economic return to that resource is the most successful tool in dealing with water shortage. The question is how to induce such behavior.

The "tyranny of the small" is a main concern (Kahn 1965). Even though each individual's act of water use, taken alone, might have a negligible impact on the allocation of water resources, the sum total can be of major importance (Young 1995).

Some specialists call for pricing irrigation water so as to induce the required change in cropping pattern. But, one reservation is that the own-price demand elasticity of water is an intermediate good in agriculture. A number of studies show demand for water to be quite price-inelastic (Young 1995; Herrington 1987; Moore, Gollehon, and Negri 1994).

The urgent issue is arid and semi arid economies have to design their policies so as to properly improve the management of their water resources.

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Figure 1: Logical Model Structure

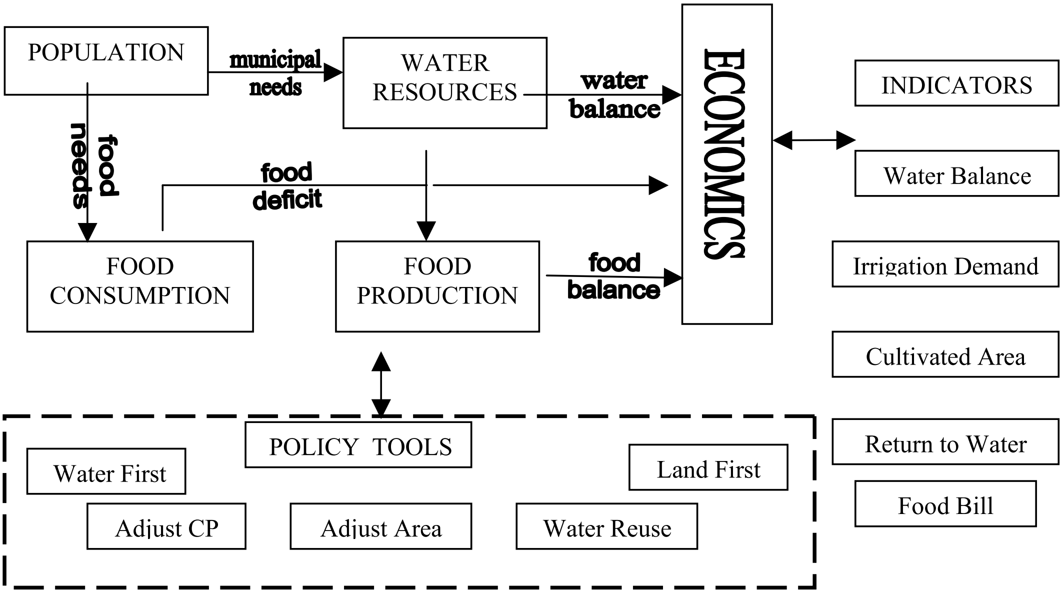


Figure 2: Water Balance Corresponding to Different Scenarios

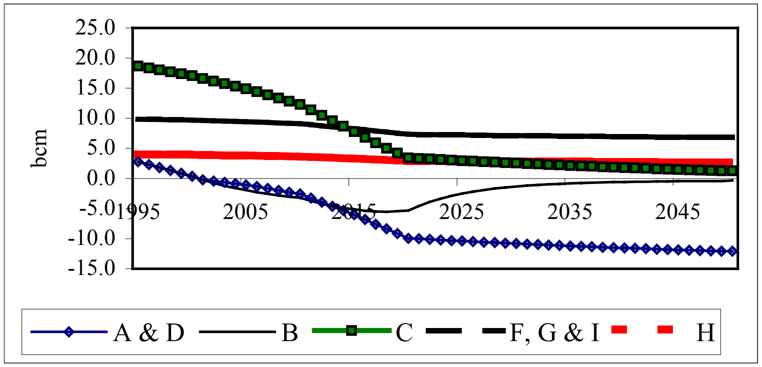
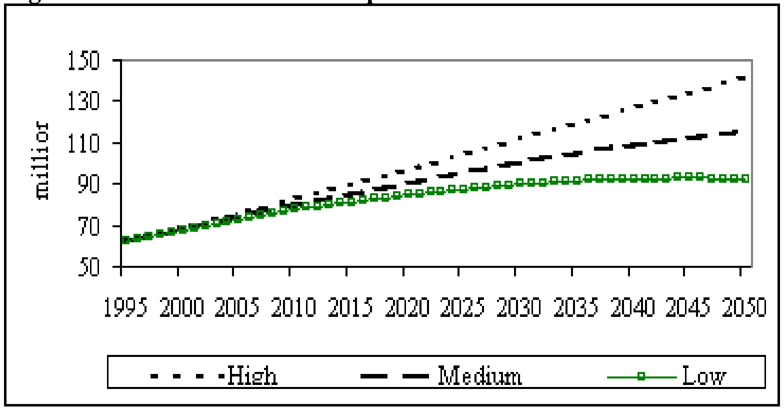


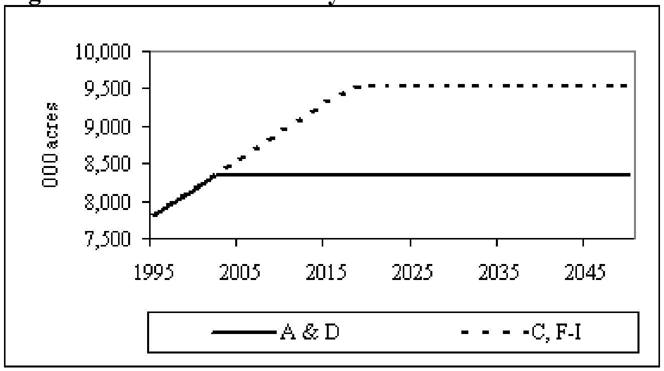
Figure 3: Three Scenarios of Population



	High	Medium	Low
1995	62.1	62.1	62.1
2000	68.6	68.1	67.7
2010	82.6	80.3	77.9
2020	96.6	90.6	84.5
2030	111.5	100.6	90
2040	126.4	108.8	92.6
2050	141.7	115.5	92.6

Source: UN 1998

Figure 4: The Effect of Policy Intervention on the Cultivated Area



	A & D	*C, F-I*
1995	7813	*7813*
2000	8188	*8188*
2010	8338	*8938*
2020	8338	*9538*
2030	8338	*9538*
2040	8338	*9538*
2050	8338	*9538*

Figure 5: Interaction Between Water Balance and Cultivated Area

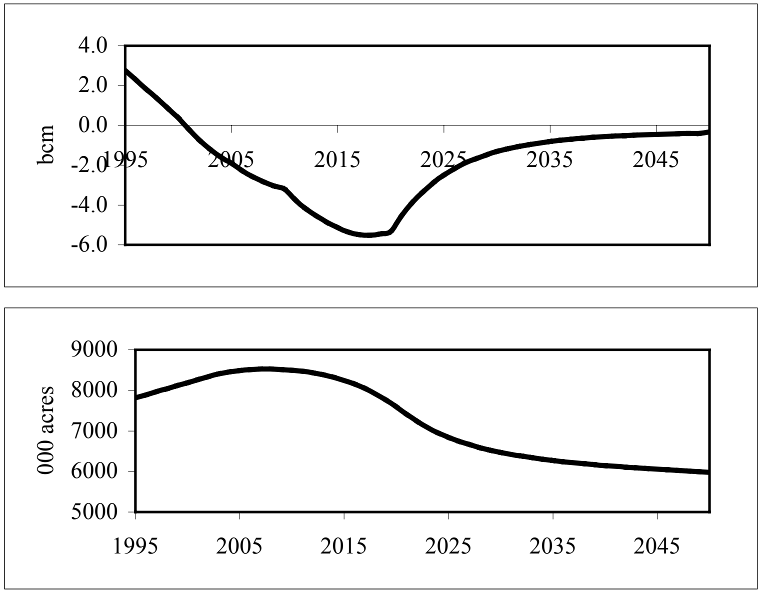


Figure 6: Total Return to Water Under Different Simulation Scenarios